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River mouth dynamics of Swarnamukhi estuary, Nellore coast, southeast coast of India

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ABSTRACT

Swarnamukhi is an east flowing river having a total length of 130 km. This is an independent river which rises at an elevation of 300 m in the eastern Ghats ranges near Pakala village in Chittoor district of Andhra Pradesh, India. This study was carried out using multitemporal satellite images of IRS P6 LISS-III and Landsat 8 OLI/TIRS data from 2011 to 2015. The subsequent short term river mouth dynamics, coastal erosion and accretion rates have been calculated for the years between 2011 and 2015. Low river inflow, wind, tides, movement of the waves and littoral currents play a key role in the dynamic activities of erosion and accretion. The erosion rate from 2011 to 2015 was slightly decreased from 0.081 to 0.027 km^2. The total net rate of accretion was estimated at 0.438 km^2. The study shows during last five years (2011–2015) accretion is more than the erosion. High fluctuation of erosion and accretion are characteristics for the short term scale at river mouth.

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1. Introduction

River mouth is a natural and tactical checkpoint that exhibits a large scope of physical, sedimentological, optical, and biological conditions and also estuary entrance is one of the most critical variables controlling the hydrodynamics and broader environmental processes of the estuary [1]. The change on shore line is mainly associated with waves, tides, winds, periodic storms, sea-level change, the

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geomorphological processes such as erosion and accretion and human activity [2]. Accordingly, the changes of coastline can directly impact on the shoreline positioning [3]. On an average, about 40% of Indian coastline is facing varying degree of erosion. From last 25 years data (1990–2014), it observed that about 25–33% of Andhra Pradesh shoreline is experiencing erosion of various magnitudes. Especially in estuaries, the river mouth was periodically change its shape and size during low river flow conditions combined with the wave-driven onshore movement of marine sediments [4]. Due to the effect of the river sediment material discharge and the action of the sea water, the sand bars are formed at the river mouth by sediment deposits in the most variable delta areas to change river mouth shape and size [5].

The formation of a bar, its size and shape depend on the intensity of sea and fresh water interaction process taking place at the mouth of the river [6]. Such factors as ocean currents, wave activity, tidal streams, sea level rise, and so on, can in a number of instances prevent the establishment of a large delta [7]. However, bars are usually formed even under similar environmental factors and the bar features can be drawn almost at any river mouth [8]. Moreover, these environments provide critical habitat to the marine biota [9]. Shoreline change detection and measurement is an important task in environmental monitoring and coastal zone management [10].

Periodic and precise observation of Earth's surface features for change detection is extremely significant for understanding interaction and relationships between human and natural phenomena in order to encourage better decision making for developmental activities [11,12]. Various methods have been used to monitor and map changes in shoreline location can be undertaken using several different techniques of data collection [13]. Remote sensing satellite data having the ability to provide comprehensive, synoptic view of fairly large area at regular interval with quick turnaround time integrated with Geographical Information System (GIS) makes it appropriate and ideal for monitoring and studying river erosion and its bank line shifting [14–16]. Many authors have used these remote sensing and geographical information techniques to demarcate the changes for some major rivers [17,18]. Remote sensing technology provides a satellite image with synaptic coverage on a large field with high spatial resolution to identify shoreline changes and delineating various factors at national, regional and local level [19,21]. Computer based image processing or signal processing merely involved to enhance the image or picture, but the algorithm correlated with the GIS that can be represent the Earth or real world features and extract the land form features from the image that may be sources of various planning and management of human sophisticated life [20].

In this study, IRS P6 LISS-III and Landsat 8 OLI/TIRS multispectral data were used to delineate the changes of Swarnamukhi River estuary. Shoreline changes in spatial and temporal aspect were analysed using remote sensing and GIS. Further, the impact of wave energy and other meteorological factors on the erosion and accretion process were also measured.

2. Study area

The Swarnamukhi is an east flowing river Basin having a little catchment area of 3225 km^2. It grows at an altitude of 300 m in the eastern Ghat ranges near Pakala village in the Chittoor district of Andhra Pradesh at 13° 28′N and 79° 09′E. It runs generally in the north-eastern direction passing through the famous Tirupati Hills before joining into the Bay of Bengal. Its total length is 130 km. This is an independent river and receives no major tributaries and therefore its flow depends only on rainfall in its upper catchment. The mean annual rainfall in the Swarnamukhi Basin decreases from 1270 mm at the eastern extremity of the basin to 762 mm at the western extremity. The north-east monsoon sets in the month of October and draws back before November. The average maximum air temperature in the catchment fluctuates from 30 °C to 32 °C and least between 22.5 °C and 25 °C. Nevertheless, the streams are also struck by the tidal cycles, by the action of waves, the shore line geography and by the presence of different water masses, assuming predominantly a SW–NE direction. Fig. 1 shows the location map of the study area.

3. Methodology

The baseline map was prepared using Survey of India (SOI) Toposheet map Nos. 66B4, 66C1 and 66C5 on 1:50000 scale. The multi temporal IRS-P6 LISS-III and Landsat 8 OLI/TIRS images acquired for the period between 2011 and 2015 were used as primary data source for shore line extraction. The images used here for analyses were of different satellite types with different sensors and spatial resolutions (Data details in Table 1). Then each image was cropped using area of interest cropping method. The cropped images were geometrically corrected by using the auto-sync tool in ERDAS Imagine 9.1 software by applying the UTM-WGS 84 projection and coordinate system [21]. After geometric corrections, all the images were processed digitally using the Water Index Method [20,22]. This method provides a sharp edge between water and land. Shoreline positions were digitized manually with ArcGIS for several dates, i.e. October-02-2011, March-18-2012, May-01-2013, November-09-2013, May-20-2014, September-09-2014, December-14-2014 and May-07-2015.

Shoreline position was exported to ArcGIS with attribute fields that included object ID, name, date, area and feature characteristics. These multidated shape files of shorelines were overlaid together for the identification of shoreline changes (shift towards either offshore or onshore). Then, the intersection of shoreline line geometry was converted into polygon geometry using the feature to polygon conversion tool in ArcGIS 9.3 for the estimation of erosion and accretion along the study area [23].

4. Results and discussions

Detection of shoreline changes were quantified from two aspects: periodic river mouth dynamics and erosion and

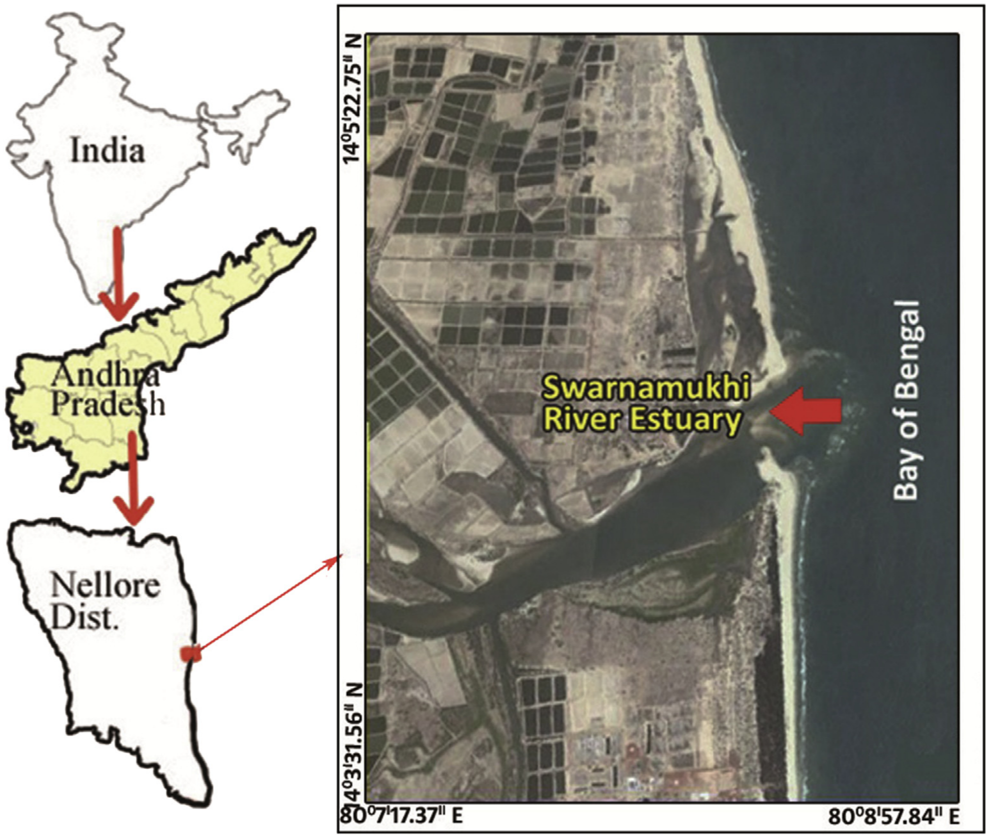

Fig. 1 — Location map of the study area.

Table 1 — Salient characteristics of satellite data used.

Name of the satellite	Date of acquisition	Sensor	Path	Row	Resolution	No. of bands
IRS-P6 (Resourcesat-1)	October-02-2011	LISS-III	102	063	23.5 m	4
IRS-P6 (Resourcesat-1)	March-18-2012	LISS-III	102	063	23.5 m	4
Landsat 8	May-01-2013	OLI/TIRS	142	050	30 m	11
Landsat 8	November-09-2013	OLI/TIRS	142	050	30 m	11
Landsat 8	May-20-2014	OLI/TIRS	142	050	30 m	11
Landsat 8	September-09-2014	OLI/TIRS	142	050	30 m	11
Landsat 8	December-14-2014	OLI/TIRS	142	050	30 m	11
Landsat 8	May-07-2015	OLI/TIRS	142	050	30 m	11

accretion of the study area for a period of five years from 2011 to 2015 using remote sensing and GIS.

4.1. *Periodic river mouth dynamics*

Remotely sensed multi-date image analysis revealed that sandbar across the river mouth is highly dynamic. The multi temporal IRS-P6 LISS-III and Landsat 8 OLI/TIRS images acquired from 2011 to 2015 were used in this study.

In Fig. 2, November-09-2013 is the only date when the river mouth closure was observed during the observed period. The mild accretion is due to the angle of the wave approach and littoral current which transports the suspended sediments from the adjacent area tends to deposit in the river mouth and thereby closed it. The remaining images of different periods showing that the river mouth was opened with significant displacement of opening point.

In this study, October-02-2011 opening point was taken as a standard point and with respect to it the displacement was measured (Fig. 3 & Table 2). In the image dated on March-18-2012 shows that the river has two mouth opening points and these two opening points were separated by an island. These two openings have the distance from October-02-2011 to March-18-2012, A and B (earlier and later openings) are 0.120 km (northern direction) and 0.219 km (southern direction) respectively. On May-01-2013 it is observed that the river mouth has shifted significantly around 0.586 km towards north. On May-20-2014, September-09-2014, December-14-2014 and May-07-2015, the displacement was

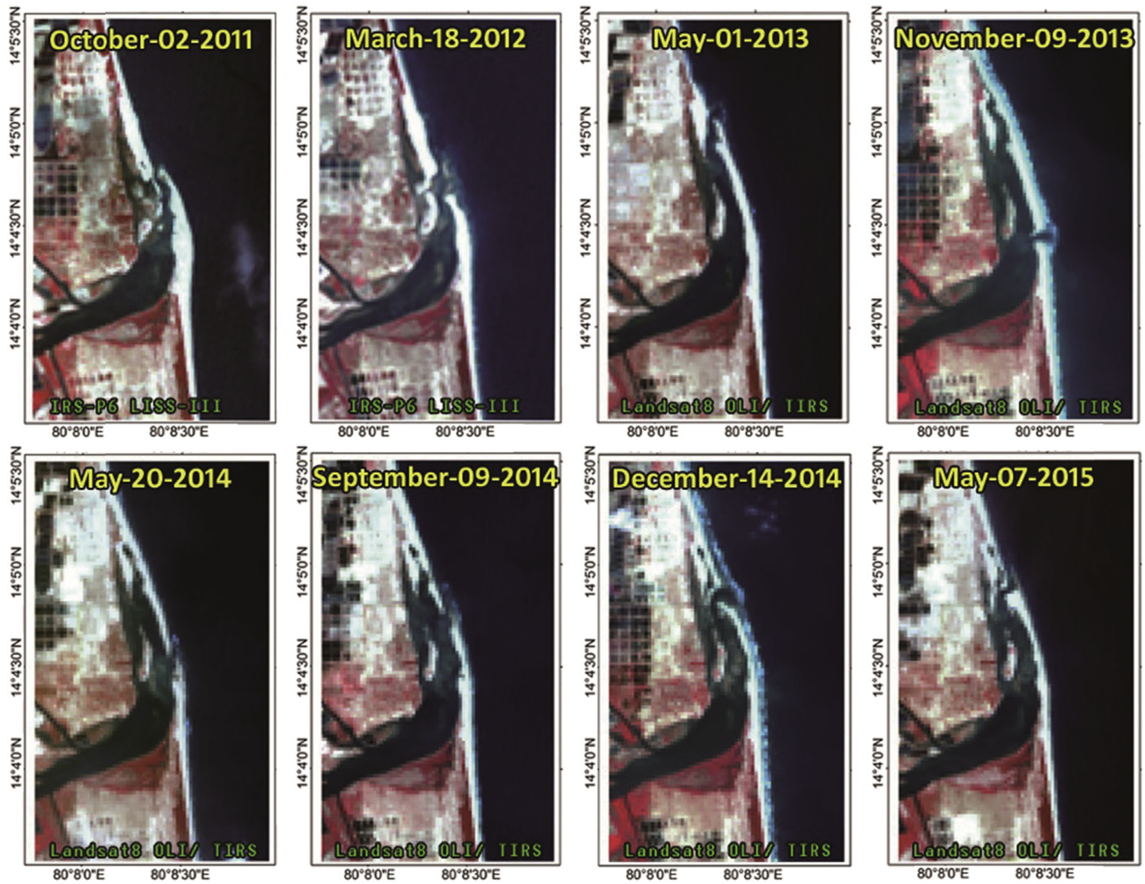

Fig. 2 – Satellite images showing the dynamics of river mouth.

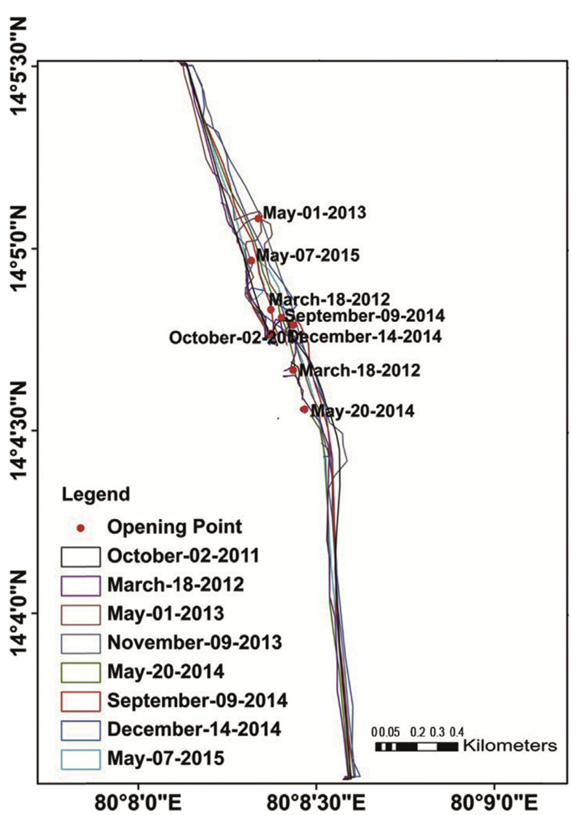

Fig. 3 – Displacement of river mouth opening.

0.438, 0.100, 0.160 and 0.403 km respectively. Field observations revealed that these deposits across the river mouth are silt, clay and mud flats with fine sand. Instability of the sandbar motion under the action of water waves is the main factor for this river mouth dynamics. The prevailing northern wind causes an oblique wave approach to the shoreline and it also causes shifting the position of the river mouth.

4.2. *Erosion and accretion*

In this study erosion and accretion rates along the study area was estimated using remote sensing and GIS techniques from the satellite images of 2011–2015 and shown in Table 3.

Table 2 – Displacement of river mouth on kilometers (October-02-2011 was base for all the above distances).

S. No.	Date	Distance of displacement in km	Direction
1.	March-18-2012 (1)	0.120	Northern
2.	March-18-2012 (2)	0.219	Southern
3.	May-01-2013	0.586	Northern
4.	November-09-2013	Closed	–
5.	May-20-2014	0.438	Southern
6.	September-09-2014	0.100	Northern
7.	December-14-2014	0.160	Eastern
8.	May-07-2015	0.403	Northern

Table 3 – Coastal erosion and accretion during 2011 and 2015.

Duration	Erosion (km^2)	Accretion (km^2)
October-02-2011 to March-18-2012	0.081	0.096
May-01-2013 to November-09-2013	0.047	0.175
May-20-2014 to September-09-2014	0.059	0.114
December-14-2014 to May-07-2015	0.027	0.053
Total net change	0.214	0.438

In Fig. 4(a) blue colour shows the erosion from October-02-2011 to March-18-2012 and violet, green and red colours show the erosion from May-01-2013 to November-09-2013, May-20-2014 to September-09-2014 and December-14-2014 to May-07-2015 respectively. Considering the changes, highest erosion occurred at estuary. The total net rate of erosion was estimated at 0.214 km^2.

The sand bars and beach ridges along this coastal zone have been formed due to wave action. Further, the short term analysis was carried out to estimate the rate of erosion separately from 2011 to 2015. Between, October-02-2011 to March-18-2012 heavy erosion was noticed with an average of 0.081 km^2 and also during May-01-2013 to November-09-2013, May-20-2014 to September-09-2014, and December-14-2014 to May-07-2015, the erosion was reported 0.047 km^2, 0.059 km^2 and 0.027 km^2 respectively. The erosion rate from 2011 to 2015 was slightly decreased from 0.081 to 0.027 km^2.

In Fig. 4(b) blue colour shows the accretion from October-02-2011 to March-18-2012 and violet, green and red colours shows the accretion from May-01-2013 to November-09-2013, May-20-2014 to September-09-2014 and December-14-2014 to May-07-2015 respectively. Between, May-01-2013 to November-09-2013 heavy accretion was noticed with an average of 0.175 km^2 and also during October-02-2011 to March-18-2012, May-20-2014 to September-09-2014 and December-14-2014 to May-07-2015 the accretion was reported 0.096 km^2, 0.114 km^2 and 0.053 km^2 respectively. The total net rate of accretion was estimated at 0.438 km^2. Accretion with sand deposition was caused by the wind, tides, the movement of the waves and longshore current. Wind direction, wind speed and wave action play a significant role in the sand deposition along the coast in the study area.

The study shows that during the last five years (2011–2015) comparatively accretion is more than the erosion (Fig. 5). Highly fluctuating erosion and accretion characters in the short term scale are more predominant at the river mouth.

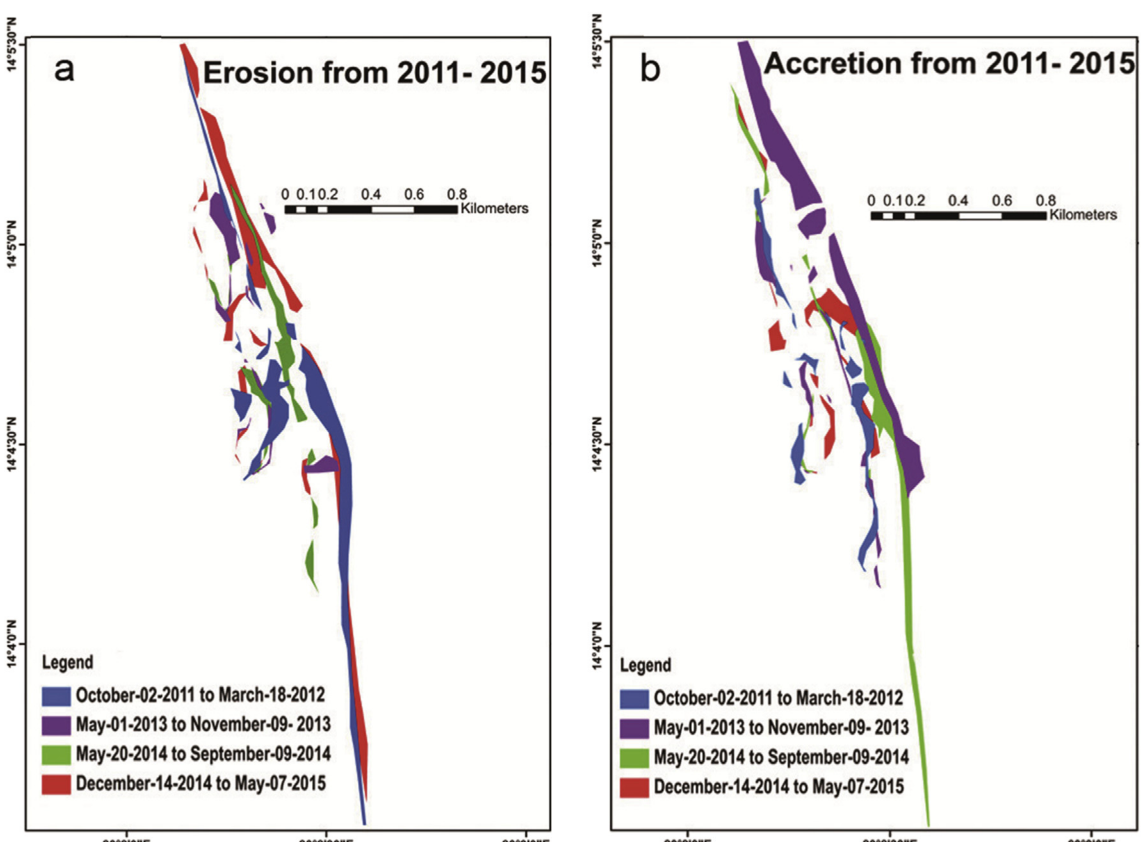

Fig. 4 – Coastal erosion and accretion during 2011–2015.

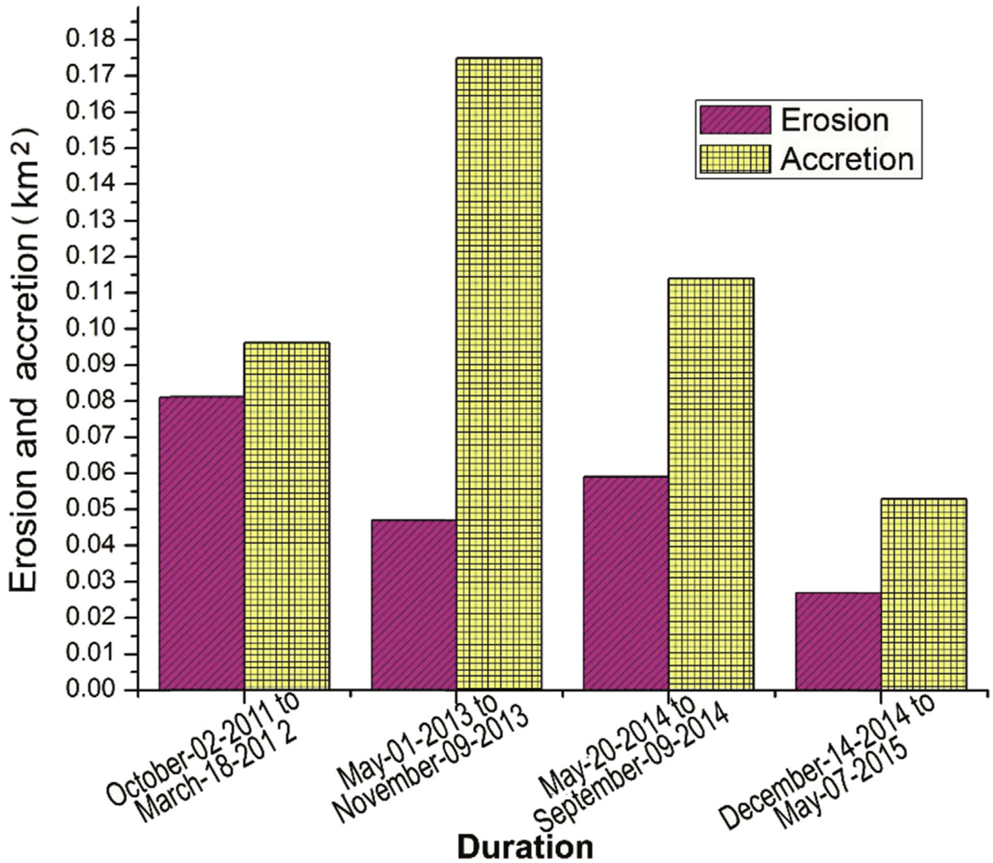

Fig. 5 – Graphical representations of coastal erosion and accretion during 2011–2015.

4.3. *Factors influencing the coastal dynamics*

Coastal dynamics are the marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system environment [24]. Waves and currents are the main fac-tors which play the most significant role in controlling sediment migration and deposition. Both waves and currents are mainly generated by, and dependent on, wind conditions. Wind-generated waves are the most important energy input into the littoral zone and, together with wave-generated currents; they are responsible for coastal erosion and accretion.

In order to assess the factors influencing the coastal dynamics (river mouth dynamics, erosion and accretion) of Swarnamukhi River, we have used meteorological factors like wind direction, wind speed, atmospheric pressure and temperature during the seven days prior to each satellite image (Table 4). It was shown that wind strength plays a key role in

Table 4 – Meteorological factors for seven days before each recorded satellite image of Swarnamukhi River estuary.

Image date	Date of meteorological data MM/DD/YY	Temperature (°C)	Wind direction	Wind speed (m/s)	Atmospheric pressure (millibars)
	09/26/2011	31.94	207.2	0.97	1008
	09/27/2011	29.88	205.8	1.02	1007
	09/28/2011	29.55	264.9	0.51	1007
	09/29/2011	28.88	359.2	0.77	1007
	09/30/2011	31	359.2	0.51	1007
	10/01/2011	31.50	359.2	0.87	1007
October-02-2011	10/02/2011	32.27	359.2	0.77	1007
	03/12/2012	28.83	359.2	1.23	1011.8
	03/13/2012	29.83	359.2	1.33	1011.7
	03/14/2012	29.61	359.2	0.92	1012

Table 4 – (continued)

Image date	Date of meteorological data MM/DD/YY	Temperature (°C)	Wind direction	Wind speed (m/s)	Atmospheric pressure (millibars)
	03/15/2012	29.38	359.2	0.97	1011.7
	03/16/2012	29.38	359.2	0.97	1011.3
	03/17/2012	29.16	359.2	1.08	1010.1
March-18-2012	03/18/2012	29.05	210.2	0.82	1010
	04/25/2013	37.38	198.9	1.33	1002.1
	04/26/2013	36.88	219.9	1.64	1001.8
	04/27/2013	36.88	225.2	2.46	1001.8
	04/28/2013	34.16	359.2	1.80	1004.1
	04/29/2013	33.88	359.2	1.64	1004.3
	04/30/2013	35.22	257.8	1.85	1002.3
May-01-2013	05/01/2013	32.61	341.2	1.13	1003
	11/03/2013	25.88	359.2	0.51	1012.9
	11/04/2013	27.16	359.2	1.54	1014.4
	11/05/2013	27.16	100.2	1.08	1014.3
	11/06/2013	27.33	86	1.23	1013.8
	11/07/2013	26.88	359.2	0.87	1012.7
	11/08/2013	27.11	71.8	0.77	1011.8
November-09-2013	11/09/2013	27.05	346	0.82	1011.5
	05/14/2014	34.55	359.2	1.54	1005
	05/15/2014	35.83	359.2	1.28	1004
	05/16/2014	35.38	359.2	1.80	1005
	05/17/2014	34	359.2	1.28	1006
	05/18/2014	32.72	359.2	1.33	1006
	05/19/2014	32.16	359.2	1.13	1006
May-20-2014	05/20/2014	32.61	359.2	0.87	1006
	09/03/2014	29.72	21	1.13	1006.5
	09/04/2014	28.88	34.2	0.97	1007.3
	09/05/2014	30.94	26.9	1.59	1006.5
	09/06/2014	29.61	40.1	1.74	1005.2
	09/07/2014	29.94	78.2	1.69	1005
	09/08/2014	30.61	41.1	1.33	1006.7
September-09-2014	09/09/2014	31.72	113.9	1.80	1007.2
	12/08/2014	26.72	359.2	0.82	1012.6
	12/09/2014	27.72	359.2	1.13	1012.9
	12/10/2014	24.22	359.2	0.82	1013.3
	12/11/2014	25.61	359.2	0.77	1013
	12/12/2014	25.33	359.2	1.08	1013.9
	12/13/2014	26.5	359.2	0.56	1014.1
December-14-2014	12/14/2014	26.55	359.2	0.66	1013.7
	05/01/2015	33.27	335.8	1.02	1007.3
	05/02/2015	32.5	287.9	1.33	1007
	05/03/2015	30.61	359.2	0.92	1007.6
	05/04/2015	31.33	281	1.08	1008.8
	05/05/2015	31.5	359.2	0.87	1008.1
	05/06/2015	31.5	199.9	1.02	1007.3
May-07-2015	05/07/2015	31.83	359.2	1.13	1007.8

sand volume transport. The prevailing northern wind causes an oblique wave approach to the shoreline and generates a westward littoral transport (Fig. 6). Strong wind blowing above 2–3 m/s are the most effective and such winds are predominant during the study period. The atmospheric pressure has been reported low during the river mouth closures. The average temperature was recorded as 30.53 °C. Finally, low atmospheric pressure, strong onshore winds and large waves are the factors to the development of elevated water levels which allow larger waves to transport sand to the shoreline tends to deposit these sediments in the river mouth and thereby closed it.

5. Conclusion

Coastal dynamics of Swarnamukhi River estuary using remote sensing and GIS provides a viable source of data for monitoring and to assess the coastal changes. This study revealed that the rate of erosion and accretion reflects coastal dynamics and the loss or gain of sediments causes the formation of young beaches, berms, sand dunes and seacliffs depending on wave energy and littoral currents. During the last five years (2011–2015) comparatively accretion is more than erosion which tends to deposit the sediments in the river

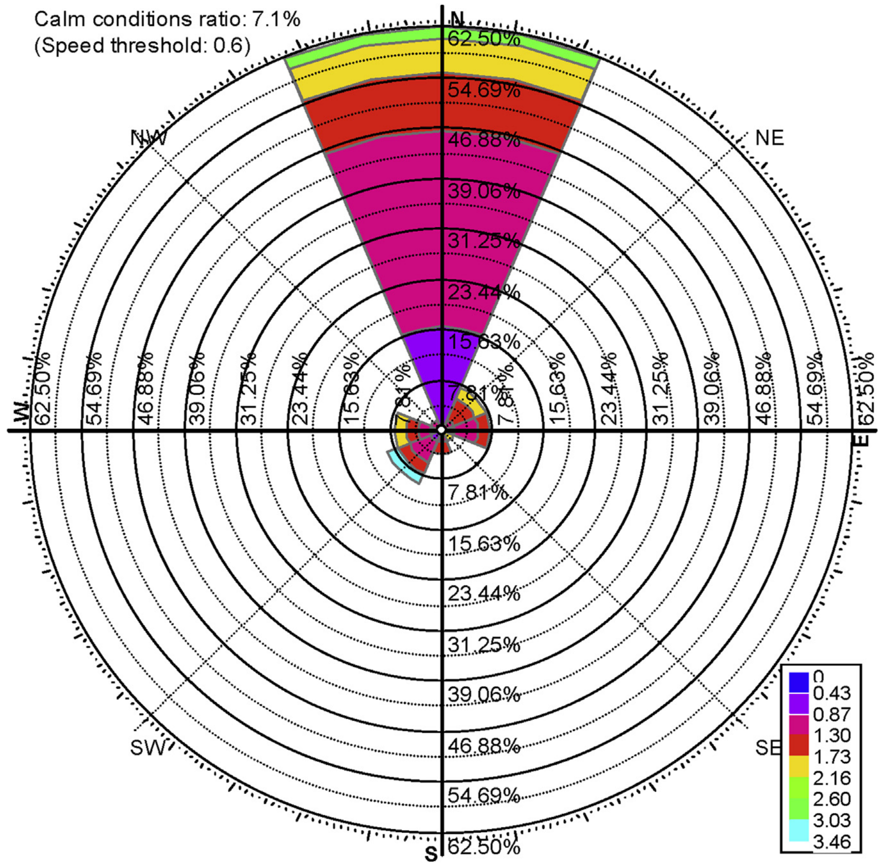

Fig. 6 – Wind rose diagram showing the relative frequency of wind direction and speed for seven days before each recorded satellite image of Swarnamukhi River estuary from 2011 to 2015.

mouths and thereby causing the closure of it and also changes of size and shape of the river mouth. It is observed that the prevailing northern wind causes an oblique wave approach to the shoreline and it causes shifting the position of the river mouth. The study area comprises its high level of agricultural and aquacultural activity. Therefore, protection work must be needed.

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